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THE OBSERVATION OF A CORONAL TRANSIENT DIRECTED AT EARTH

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ABSTRACT

Previous observations of coronal transients have led to conflicting interpretations of their morphology. Observed projections of these optically thin plasma disturbances on the plane of the sky at the solar limb have been variously interpreted as exhibiting looplike (planar) and bubble-like (three-dimensional) structures, generating widely divergent theoretical conclusions as to the nature of causative mechanisms. Here we report the observation of a large coronal transient that can only be interpreted as a three-dimensional structure. Its form is one which has not been observed before—a gradually expanding, Sun-centered disk of excess brightness, whose projected radius increased from 4 $R_{\odot}$ to 8 $R_{\odot}$ during 0832–0958 UT on 1979 November 27. This Earth-directed transient originated with the sudden disappearance of a large filament at N05W03 (0540–0703 UT, November 27) and a relatively minor (1N) solar flare at N18E05 (0647 UT). It was the source of an interplanetary shock that reached *ISEE 3* at 0649 UT, November 30, and Earth at 0738 UT, November 30. Fitting the shock speed at *ISEE 3* and the average transit speed from the Sun to *ISEE 3* to a power law of the form $V = V_0 r^{-n}$, we find that $V_0 = 1980$ km s^{-1} and $n = 0.294$, in good agreement with shock wave models. The speed of the shock predicted by the power law at 10 $R_{\odot}$ is 1000 km s^{-1}, which agrees with the estimated frontal speed of the transient.

Subject headings: interplanetary medium — shock waves — Sun: corona — Sun: solar wind

I. INTRODUCTION

White-light coronal mass ejections (MacQueen 1980) can only be observed projected onto the plane of the sky. Thus, little information is available regarding the three-dimensional nature of these coronal transients. From a study of the numerous looplike transients observed with the High Altitude Observatory coronagraph on the *Skylab Apollo* Telescope Mount, Trottet and MacQueen (1980) suggested that coronal transients are planar structures with relatively little depth along the line of sight. However, Crifo, Picat, and Cailloux (1983), from a polarization analysis of the legs of a *Skylab* coronal transient, found that the degree of polarization in the legs supported a bubble or three-dimensional interpretation for the ejected material. It is of interest to distinguish between these two geometrical interpretations because they correspond to two entirely different classes of mechanisms that have been proposed for the transient dynamics.

By no means are all transients observed as expanding loops—only about 35% of the transients observed during the *Skylab* era were loops (Munro *et al.* 1979). Many are seen as outward propagating broad fans containing two or more bright "radial" legs, with only a diffuse, formless leading edge. Single narrow outward propagating spikes are also seen.

With this *Letter* we report the observation of a completely new coronal transient form—a halo of excess brightness completely surrounding the occulting disk and propagating radially outward in all directions from the Sun. Combining the transient observations with the correlative solar, solar wind, and terrestrial observations, we conclude that this transient is (1) a three-dimensional structure, (2) directed toward the Earth, and (3) associated with an interplanetary shock wave.

II. OBSERVATIONS

a) *Coronal Observations*

The coronal transient was observed with the Naval Research Laboratory's white-light coronagraph, Solwind, on the Department of Defense Space Test Program satellite *P78-1*. The instrument characteristics have been described elsewhere (e.g., Michels *et al.* 1980*a*). Briefly, the instrument images the corona from about 2.5 to 10 $R_{\odot}$ with an angular resolution corresponding to 1'.25 per pixel. Polarizing material, cemented to the vidicon faceplate, is used to determine the degree of polarization of the K coronal brightness at several radial positions and thereby gives the location of a transient with respect to the plane of the sky (Poland *et al.* 1981).

On 1979 November 27 the coronagraph observed the sequence of images displayed in Figure 1 (Plate L5). The transient has been enhanced in these images by digitally subtracting the background corona. We define the background corona to be that observed on an image during the previous orbit (96 minutes earlier), before the transient occurred. Image noise was filtered using the algorithm of Lee (1981), and the contrast was then increased to produce the final images.

The first image of the coronal transient at 0822 UT shows a region of excess brightness nearly surrounding the occulting disk in a "halo." The dark region centered at about 30° N on the east limb is the shadow position of the pylon which supports the occulting disk. The excess brightness describes an approximately circular pattern of about 4 $R_\odot$ radius. The next five images show the circular pattern gradually expanding to 8 $R_\odot$.

Figure 2 gives a height-time diagram of the leading edge of the pattern. Because the leading edge is somewhat diffuse and of low brightness, a precise determination of its position is somewhat difficult. To within an accuracy of about ± 50 km s^{-1}, a constant outward speed of 600 km s^{-1} is characteristic of all position angles. There is a suggestion for deceleration beyond 7 $R_\odot$ (projected onto the plane of the sky) at 0958 UT, but the uncertainty in defining the leading edge does not justify a conclusive statement at this single observation time.

An estimation can be made of the heliocentric angle of the emission cone of the transient. If we assume that the speed is constant and that the boundary of emission forms a cone of constant angular spread, centered on the center of the Sun, then we can calculate a frontal speed of about 1160 km s^{-1} and an angular spread of 27° between the edge of emission and the center of the cone.

A polarization analysis has not yet been completed. However, from Figure 1 one can see that the attenuation of the signal in the polarizing rings (oriented to block transmission of light with the electric field vector perpendicular to the radius vector) is not very significant, especially compared with that observed for most transients (Fig. 3*a*, Plate L6). Thus, the brightness due to the transient is only weakly polarized, as would be expected for a transient far from the plane of the sky.

b) *Correlative Observations*

Due to its symmetric appearance around the occulting disk, we looked to see if the coronal transient were associated with a disturbance close to the sub-Earth point on the solar disk. Projecting back from the time of observation of the transient with a constant speed, we estimate that a causative event might have occurred at about 0715 UT. The Culgoora H$_\alpha$ patrol, with a passband of 0.5 Å, observed an importance 3 sudden disappearing filament (SDF), at N05W03, between 0540 and 0703 UT. This SDF, which was oriented to the north-south direction to less than 20°, may have been associated with a relatively minor flare (1N) in a nearby active region at N18E05 (0647 UT). At 0722 UT, another 1N flare occurred in the same active region at N14E05. Associated hectometric type II radio emission was detected by the *ISEE 3* radio spectrograph, but its analysis has not yet been completed (Bougeret, private communication).

On 1979 November 30, at 0649 UT, a shock wave was detected at the *ISEE 3* spacecraft by both the Los Alamos plasma experiment (Feldman and Gosling, private communication) and by the Jet Propulsion Laboratory magnetometer (Smith, private communication), nearly 3 days after the filament disappeared. The

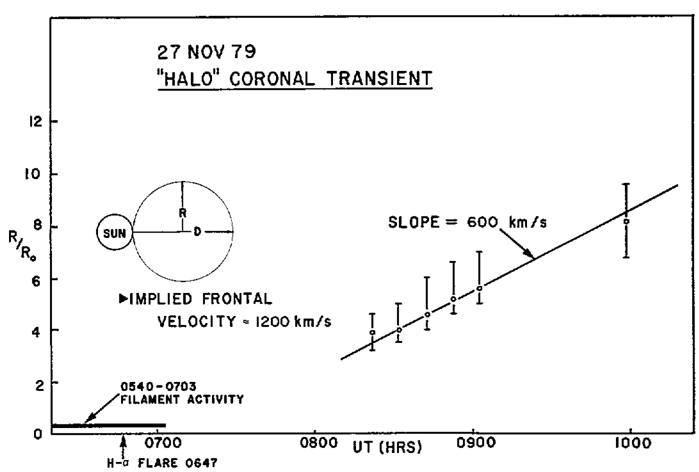

FIG. 2.—Height-time plot of the leading edge of the white-light transient. The time interval during which the filament is seen to disappear is displayed, along with the flare time, and the time interval of the radio type II burst. The error bars on the white-light observations show the variation in the projected height of the leading edge at various position angles. The slope of the straight line is equivalent to a plane of the sky speed of 600 km s^{-1}.

driver gas was not readily discernible. A storm sudden commencement was observed at Earth, 49 minutes later, at 0738 UT on November 30.

Assuming that the shock front moved along the Sun-Earth line, and using the plasma parameters given by Kennel *et al.* (1982), we calculate a shock speed of 410 km s^{-1} at *ISEE 3*. We also calculate two transit speeds of the shock. From the *ISEE 3* spacecraft to the Earth's surface, we obtain 420 km s^{-1}, and from the Sun to the *ISEE 3* spacecraft, we obtain 560 km s^{-1}. Comparing the local speed at *ISEE 3* to the two transit speeds, we conclude the following three points. The shock front is propagating along the Sun-Earth line. The speed in the vicinity of the Earth is slightly greater than 400 km s^{-1}. The shock must have decelerated in going from the Sun to *ISEE 3*.

If the deceleration were linear over 1 AU, then we would expect the shock speed at the Sun to be about 720 km s^{-1}. This is much lower than our estimate of the transient speed (about 1200 km s^{-1}). Thus, the deceleration was not constant and must have been greater near the Sun.

D'Uston *et al.* (1981) have simulated the interplanetary response to flare-related disturbances using an MHD numerical model. They found that, for their test cases, the shock speed could be fitted using a power law of the form, $V = V_0 r^{-n}$, where the exponent, n, varied between 0.3 and 0.4. For a classical blast wave (Hundhausen 1972), n is 0.5, whereas, for a decelerating piston, n is between 0.0 and 0.5 (Dryer 1975). Fitting the November 27 transient and interplanetary shock data, we obtain $V_0 = 1980$ km s^{-1} and $n = 0.294$. At 10 $R_\odot$, this formula gives a shock speed of 1000 km s^{-1}, in good agreement with our estimate of the transient speed.

Although the speed within the coronagraph field of view is adequately described, this power-law model does imply a deceleration from nearly 2000 km s^{-1} at the solar surface to 1000 km s^{-1} at 10 $R_\odot$. Such deceleration of coronal transients has not been observed with the Solwind coronagraph. Indeed, most of the transient observations do not warrant any interpretation other than that of constant speed. The remaining few cases show either acceleration or small deceleration, but no significant deceleration.

III. DISCUSSION

Trottet and MacQueen (1980) showed that the filaments associated with the *Skylab* looplike transients were oriented in a north-south direction to within 20° and were in a simple configuration. The filament associated with the November 27 transient also satisfied these conditions. However, a planar loop cannot explain the halo brightness distribution. Therefore, Trottet and MacQueen's sufficient conditions cannot be extended to be necessary conditions for the occurrence of a planar loop transient.

Perhaps the *Skylab* looplike transients were three-dimensional shells. In a recent paper, Crifo, Picat, and Cailloux (1983) concluded that the 1973 August 10 *Skylab* coronal transient was more likely to be a bubble-shaped structure than a loop. Another coronal limb transient, detected by Solwind on 1978 May 8, has been interpreted as a spherical shell of enhanced electron density behind a shock front (Wu *et al.* 1983).

Utilizing a spherical shell model, we attempt to compare, in Figure 3, the appearance of coronal transients when seen on the limb and their appearance when seen head-on. An image of the 1979 May 8 limb transient (Michels *et al.* 1980*b*) is shown in Figure 3*a* (*upper*). Here, the leading edge of the transient is seen as it was propagating radially away from the Sun. A schematic representation of this type of limb transient is shown in Figure 3*a* (*lower*). If, instead of occurring on the limb, the transient were coming toward the observer, the transient might appear as shown in the diagram in Figure 3*b* (*lower*). Here, the occulting disk is completely surrounded by emitting material. The circular front propagates radially outward. This pattern is exactly the observed pattern for the November 27 transient, as is shown in Figure 3*b* (*upper*).

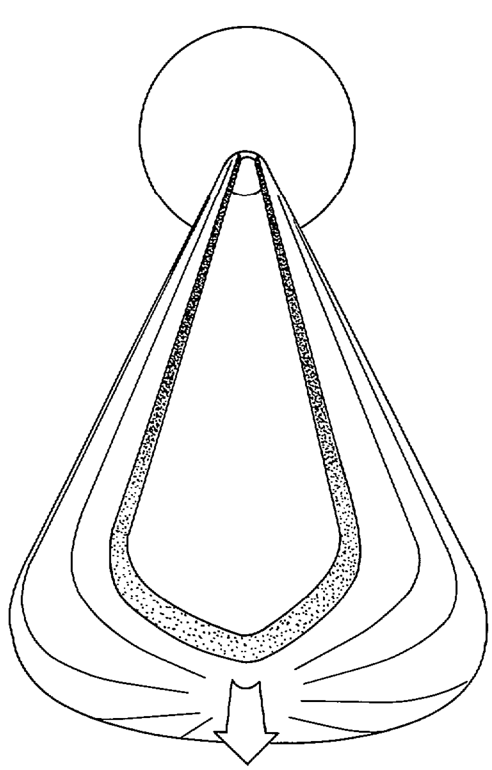

FIG. 4.—Conical shell model. This is similar to a spherical shell model except that here the front makes an acute angle with the sides of the cone. Edge brightening is not significant in this case, since the line-of-sight depth is small compared with the thickness of the shell.

However, a simple spherical shell is not able to provide a complete explanation of the observed brightness distribution. If the front is a relatively thin spherical pressure wave, then the edge is expected to be brightened relative to the central region since the path length along the line of sight over which Thomson scattering takes place is increased. No such brightening is observed.

One possible explanation of the discrepancy is that the inner cavity is filled with plasma. This would explain the November 27 observations. It would also explain why most of our looplike limb transients seem to be "filled in" with emission. The 1979 May 8 transient (Fig. 3*a*) occurred in association with an eruptive prominence at the limb and produced an interplanetary shock at the *Helios 2* spacecraft (Sheeley *et al.* 1980). In the May 8 transient, the entire area bounded by the leading edge and the legs is filled with nearly structureless emission except for a small cavity behind a portion of the front. Furthermore, the front edge was no brighter than the diffuse material behind it.

It is not necessary to invoke a completely filled structure. A slightly different model also can explain the observations. It again utilizes another commonly observed transient configuration, in which the legs are relatively bright and the front is diffuse and dim. A model can be constructed (Fig. 4), consisting of a hollow conical shell of emitting material, in which the front is significantly dimmer than the sides of the cone. Such a model would not produce an edge brightening effect.

Two additional transients have emission extending over very large position angles (270°) and can be identified as the halo type. While this represents a relatively low percentage of the nearly 500 transients seen to date, it is perhaps not surprising for two reasons. First, the central axis of the cone of emission needs to be aligned along the line of sight to within 5°. If this condition is met, then the emission will surround the occulting disk in a halo of nearly constant brightness. Second, the transient mass must be fairly high to be detectable. The November 27 transient was extremely faint, about 10% above the background, yet we estimate the mass to be 2×10^{16} g, making it one of the more massive events.

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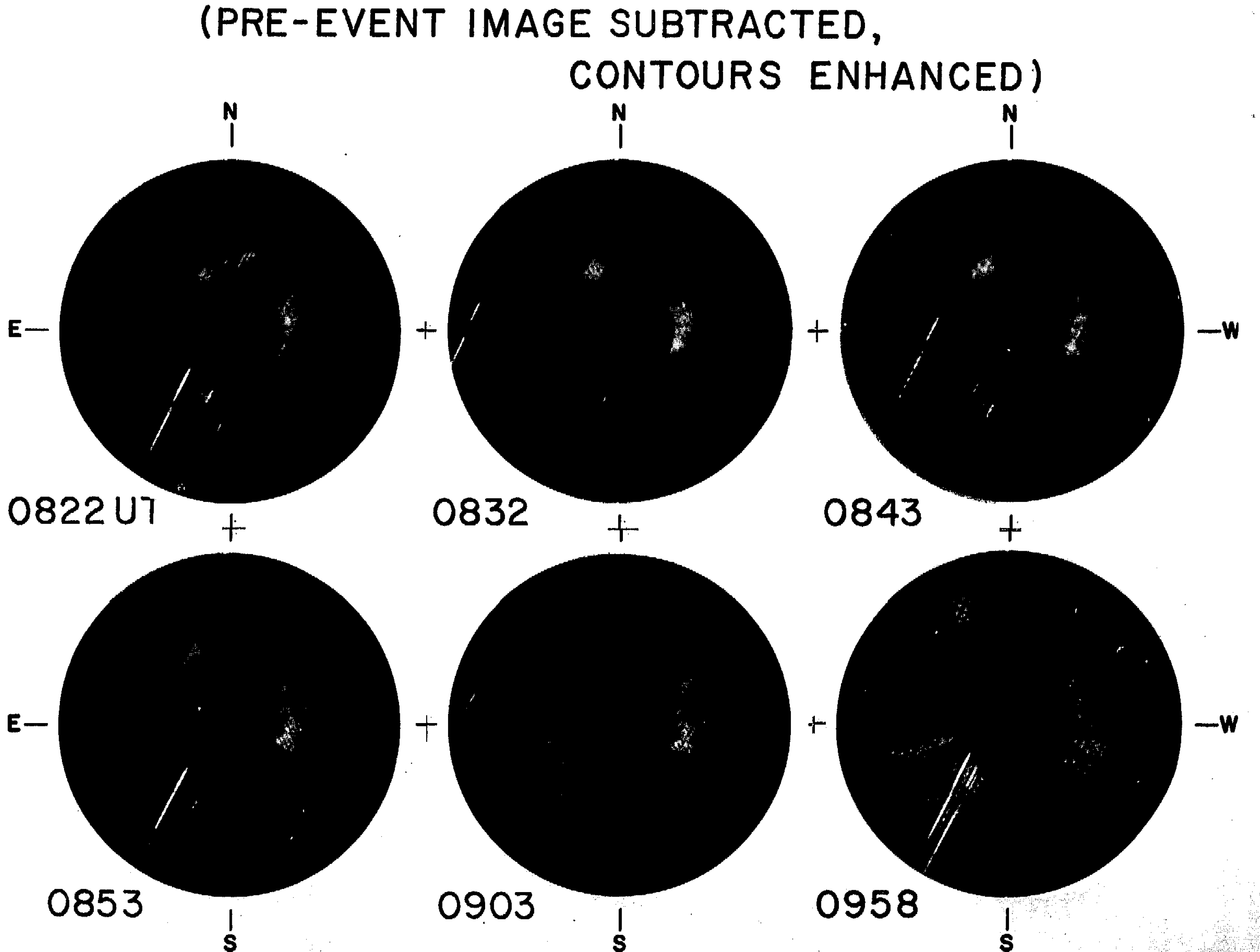

FIG. 1.—Difference images of the white-light coronal transient recorded on 1979 November 27. The difference images have been created by subtracting the background corona from the images recorded at the times noted in the figure. Except in the region where the occulting disk pylon obscures the corona, the coronal transient completely encircles the occulting disk at a radius of 4 $R_\odot$ in the 0822 UT image. By 0958 UT, the radius of the excess brightness is about 8 $R_\odot$.

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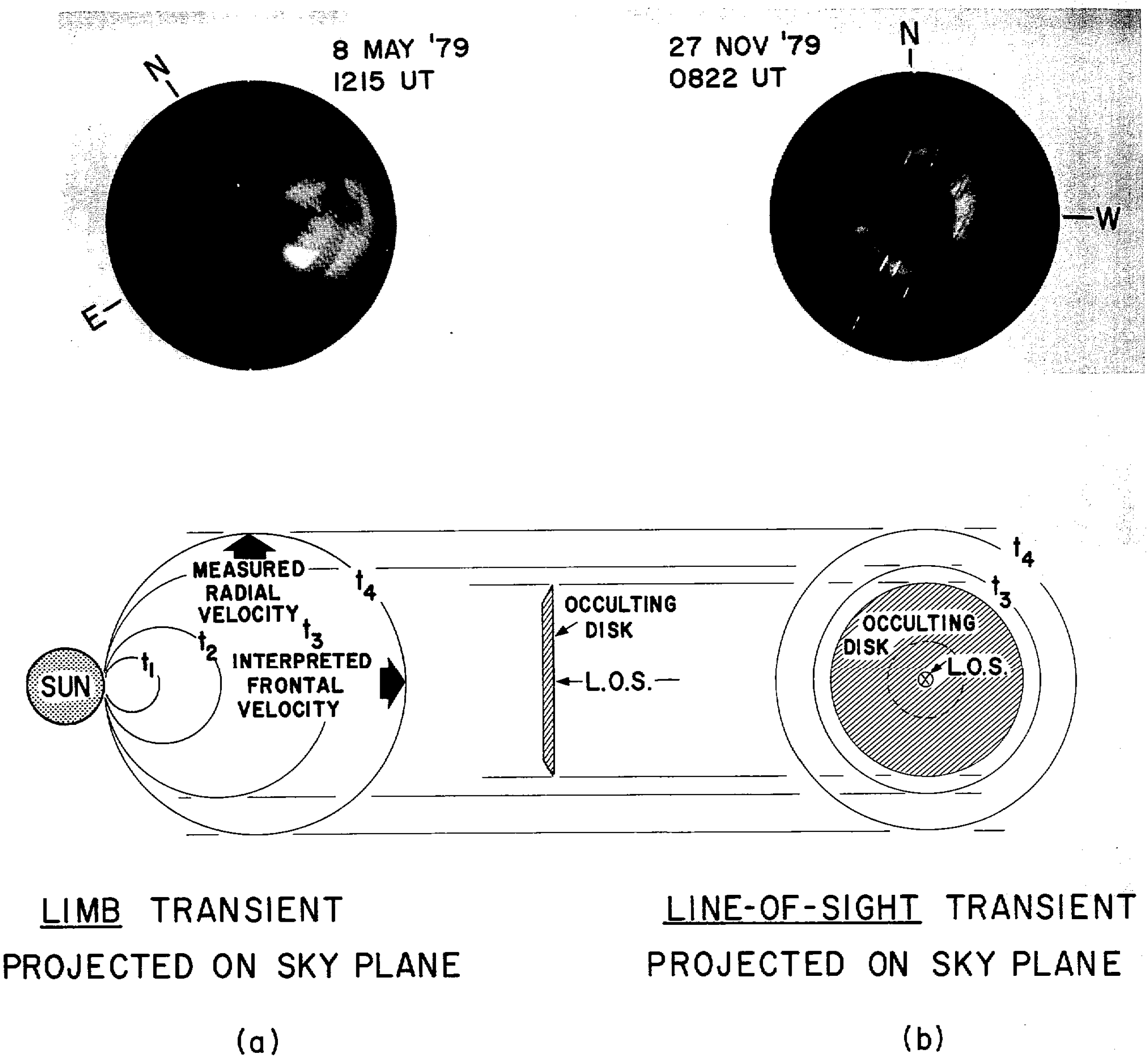

FIG. 3.—Comparison of a spherical coronal transient model for a limb transient and for a head-on transient. (*a*) The limb transient, 1979 May 8, and schematic representation for the usual viewpoint in which the line of sight is perpendicular to the direction of propagation. (*b*) The head-on transient, 1979 November 27, and schematic representation for the new viewpoint in which the line of sight is aligned with the direction of propagation.

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